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MEASURING DEPOSED SEDIMENT IN SMALL RESERVOIRS, CASE STUDY: "GRADČE" RESERVOIR

SUMMARY

Reservoir sedimentation is a serious consequence of soil erosion with large environmental and economic implications. On the other hand, reservoir sedimentation also provides valuable information on erosion intensity and sediment transport within a drainage basin. A reservoir can be considered as a large scale experiment, as the outlet of a giant erosion plot. With the application of the global navigation satellite system (GNSS), the bathymetric measurements of the sediment in the reservoirs became much easier. The measurements done with GNSS supported echosounder are completed much faster with considerable accuracy. Because the time needed for the measurements is much shorter then besides the measurements of the established profiles also some additional measurements can be done. Namely this new method gives the opportunity for total measurement of the reservoirs on profiles and contour measurement. The case study was done on the reservoir "Gradče" which is a small reservoir with total storage of 1.8 106 m3.The reservoir siltation was measured twice (1984 and 1991) while the latest measurement was done in 2013 with echo-sounder with GPS support. Then the total deposited sediment was calculated and the deposition rates were calculated. It was concluded that until 1984 the deposition rate was 2.5 time higher than the later period (1984-2013).The used measuring method, combination of contour and cross-profile measurement, showed promising results.

Keywords: Reservoir, Bathymetry, Echosounding, GNSS/GPS, GIS

INTRODUCTION

Reservoirs are designed to operate for a limited amount of time, but often their lifespans are reduced by sedimentation. Despite the designed life, reservoirs realistically have a project life defined as the "period during which the reservoir can reliably serve the purposes it was originally constructed for". Reaching of the project life, the failure to meet designed needs occurs typically before half of the storage volume of the reservoir is reduced from sedimentation (Morris et al., 2007; Dendy et al., 1973; Murthy, 1997). The storage capacity, or reservoir yield, is expressed "as a function of available storage volume in the conservation pool" (Nikitina et al, 2011).

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Reservoir sedimentation is a serious consequence of soil erosion with large environmental and economic implications. On the other hand, reservoir sedimentation also provides valuable information on erosion problems and sediment transport within a drainage basin. A reservoir can be considered as a large scale experiment, as the outlet of a giant erosion plot (de Vente et al, 2000).

The reservoirs are a unique category of object because their lifespan is little dependent on the constructive elements of the dam itself, but it is largely depending on the erosion and sedimentation processes. If the sediment regime is properly managed then the reservoirs can last much longer than their projected lifespan. Schnitter (1994) is in his work is emphasizing the presence of 12 reservoirs which lasted over 2000 years. Four of these dams/reservoirs are still functional (Morris et al., 2007).

The primary purpose of a reservoir sedimentation survey is to determine the volume and weight of sediment accumulated between surveys, or during the recorded period of storage. Information obtained from reservoir sedimentation surveys may be used to: estimate sediment yield for a given watershed, evaluate sediment damages, Provide basic data for planning and designing reservoirs, evaluate the effects of watershed protection measures, determine the distribution of sediment in a reservoir, and/or predict a reservoir's sediment storage life expectancy, or period of useful operation (Hall, 2010).

It is estimated that more than 0.5 percent of the total reservoir storage volume in the world is lost annually as a result of sedimentation (White, 2001). In comparison for R. Macedonia, the reservoir "Tikveš" was built in 1968 with total storage of 475 106 m^3. The last measurements of the sediments in 1991 show accumulation of 29.3 106 m^3 of deposed sediment or on average annually was deposited 1.27 106 m3 or 0.26 percent of the total storage, which is little above the European average value (Trendafilov, 1995).

All of the measurements in the past were done by the Agency for water economy of RM with echosounder without GNSS (Global navigation satellite systems) support, with established geodetic polygonal network on already established measuring profiles. This approach included: setting up a polygonal network on already established measuring profiles, then the echosounding equipment was fixed to a boat and finally the boat was moving on the established profiles and the position was determined by a geodetic instrument (distomat). This approach was very labor intensive and included mobilization of a lot of manpower.

The invent of the Global navigation satellite system, the bathymetric measurements of the sediment in the reservoirs became much easier. The latest equipment for bathymetric measurements includes echosounder with spatial support of GNSS (mainly GPS). The measurements done with GNSS supported echosounder are completed much faster with considerable accuracy. Because the time needed for the measurements is much shorter then besides the measurements of the established profiles also some additional measurements can be done. Namely this new method gives the opportunity for total measurement of the reservoirs on profiles and contour measurement.

The aim of this study is defining the regime of sedimentation within the reservoir "Gradce". The objectives of this study are: a) bathymetryc measuring b)calculation of deposed sediment c) defining sedimentation regime over time.

MATERIAL AND METHODS

The study area (Figure 1.) is situated in the North-East part of the country, near the town of Kočani. The reservoir "Gradče" is taken as a case study. The area of the catchment of the reservoir is 88.49 km^2, and the length of the longest river "Kocanska reka" is 18.62 km. The dam was built in 1959 and the total reservoir storage was 1.8106 m^3.
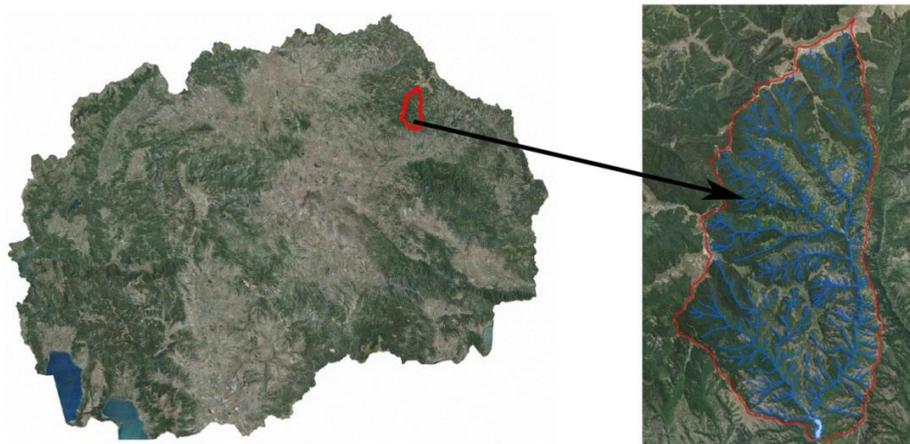

Figure 1. Position of the catchment of the reservoir "Gradče" in Macedonia

The catchment of the reservoir "Gradče" is mainly consisted of natural vegetation: forests 72.7%, meadows 17.1%, shrubs 4.7% and only 1.8% of the catchment is arable land (Figure 2).

The geology is consisted mainly from not stable schist formations and the main soil type is cambisol on the areas covered with forest and on the non-forest areas this soil type is mixed in complexes with regosol which is an indicator for its degradation. The annual total rainfall in the catchment is from 583 mm, on the lower slopes, to 1014 mm on the highest peaks or the mean value is 782 mm.

Acoustic echo-sounding relies on accurate measurement of time and voltage. A sound pulse of known frequency and duration is transmitted into the water, and the time required for the pulse to travel to and from a target (e.g., a submerged object or the bottom of a water body) is measured (Figure 3).

The distance between sensor and target can be calculated using the following equation:

$$D = (S \times T)$$

Where D = distance between sensor and target, S = speed of sound in water, and T =round-trip time.

Isohyetic map
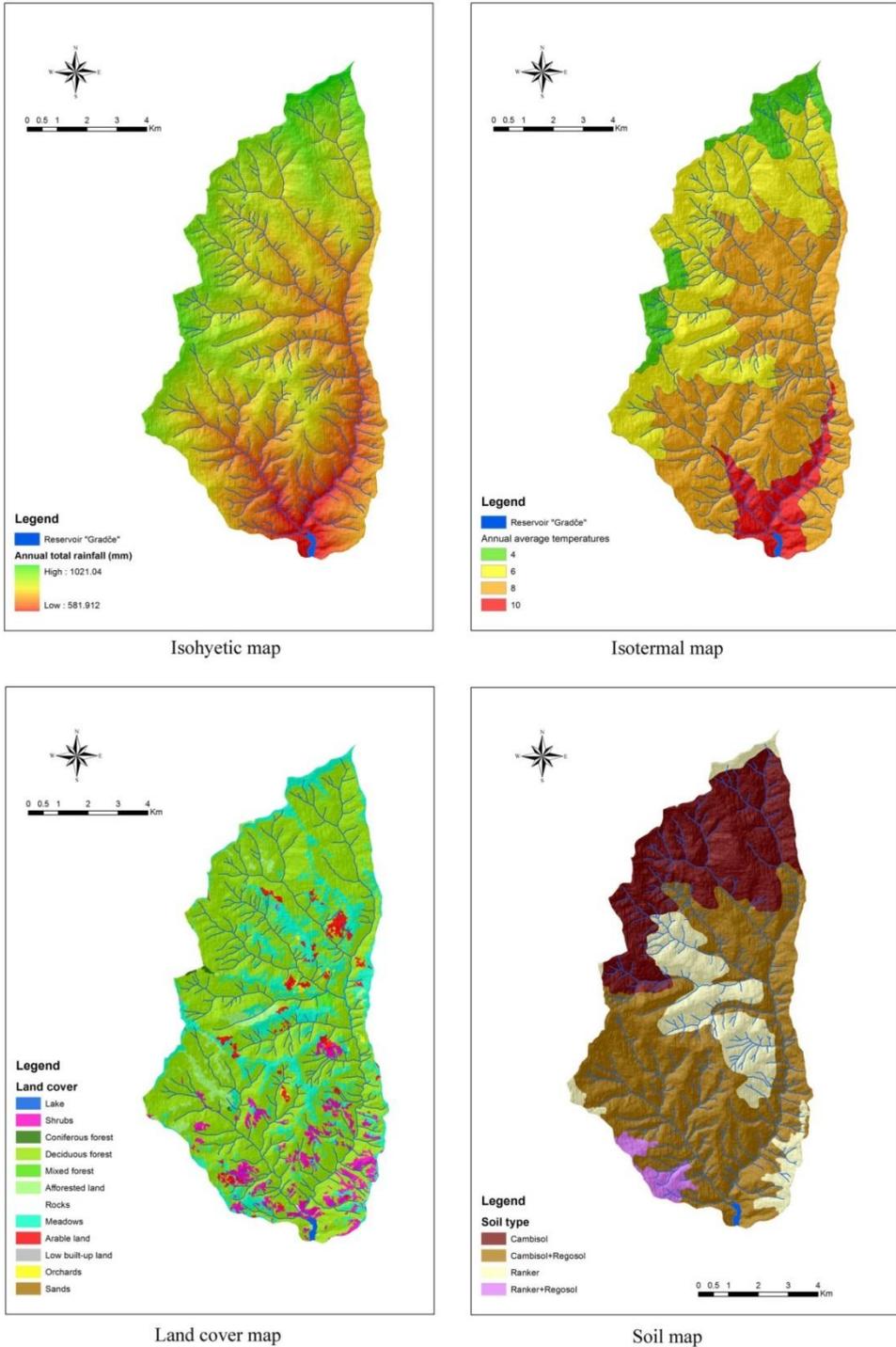
Isotermal map

Land cover map

Soil map

Figure 2. Natural conditions in the catchment of the reservoir "Gradče"
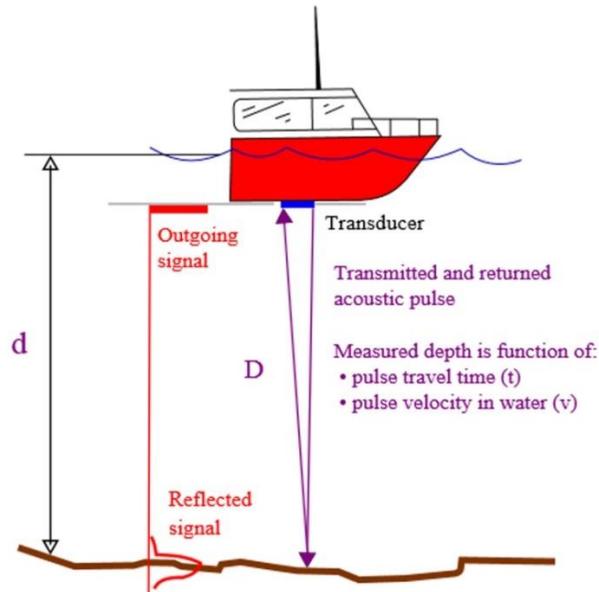
Figure 3. Theory of echo-sounding (source: Wikipedia)

To acquire information about the nature of the target, intensity and characteristics of the received signal also are measured. The echo-sounder has four major components: transducer, which transmits and receives the acoustic signal; signal generation computer, which creates the electrical pulse; the global positioning system, which provides precise latitude/longitude coordinates; and the control and logging computer. Prior to conducting a bathymetric survey, geospatial data (including geo-referenced aerial photography) of the target lake are acquired, and the lake boundary is digitized as a polygon shape file. Transect lines are predetermined based on project needs and reservoir size. Immediately before or after the bathymetric survey, elevation of the lake surface is determined (Jakubauskas and deNoyelles, 2008).

Figure 4. GPS Echo-sounder GPS Map 521s

The reservoir "Gradče" was measured for deposed sediment only two times, 1984 and 1991. The measuring was done on already established profiles. Because the reservoir is very small there were only four measuring profiles established. The first measurement was done in 1984 by the Faulty of Civil Engineering – Skopje. The measured deposited sediment was 380,000 m^3 or on average annually for the period 1959-1984 the deposition was 15,200 m^3/year. The next measurement was done by the Institute for water economy in 1991. For the period 1984-1991 there were additionally deposited another 40,165 m^3 of sediment or 5,783 m^3/year or specific 65.58 m^3/km^2/year. This means that in 1991 in the reservoir there was 420,165 m3or for the period 1959-1991 annually were deposited 13,254 m^3/year or 151 m^3/km^2/year.

For the purpose of this study it was done an additional measurement of the sediment in order to estimate the rate of filling the reservoir with sediment. The measurements were done with Color GPS chartplotter and sounder GPSMAP 521s (Figure 4). This was the main echo-sounder used for the lake bathymetry. This is not a professional echosounder and it has poor output capabilities. It was checked for accuracy on the field and it showed good results. This model has the capability of dual frequency measurements for the measuring the bottom level and the compaction of the sediment.
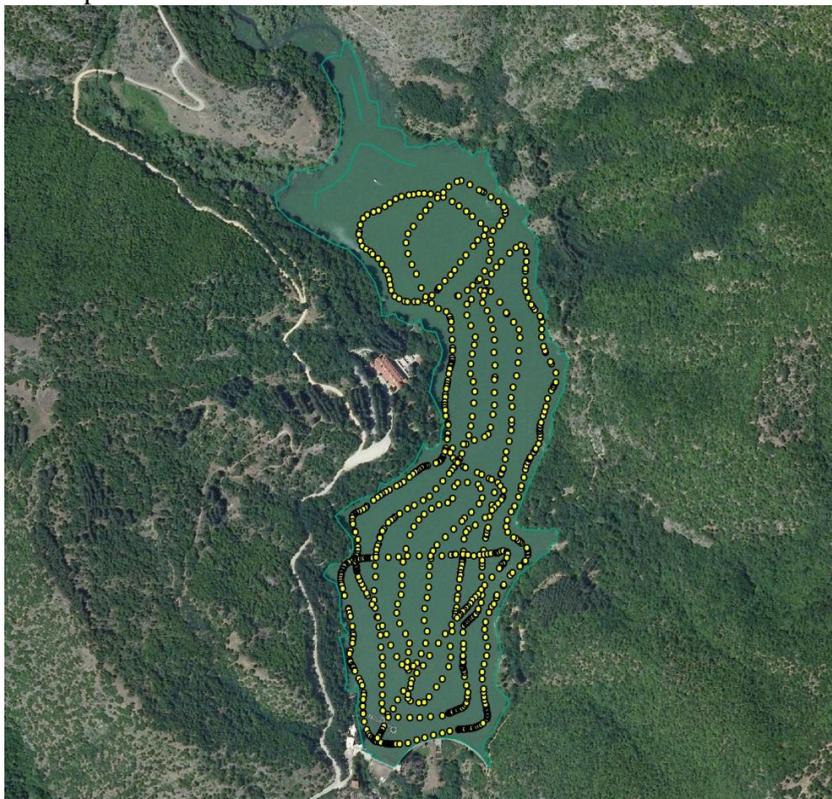

Figure 5. Measuring route

Because of the small number of measuring profiles, the reservoir "Gradče" was measured with combined contour and profile measuring routes. This method is much more accurate compared with the former because it covers not only the established measuring profiles but also the area not covered by the profiles in perpendicular direction. The down side of this method is that it takes longer time than the former but it is more accurate.

The next step was downloading the GPS route in the computer and further the analyses were done in GIS software. The measuring route was transferred as a point file with X, Y and depth. Then the normal level of the reservoir was digitized (465m) from an aerial image. Using the elevation data from the measuring route and the digitized bank of the reservoir the TIN (Triangular Regular Network) was developed. Then the total volume of water was calculated and was subtracted with the total projected volume of the reservoir in order to calculate the total deposited sediment in the reservoir.

RESULTS AND DISCUSSION

Figure 6 shows the developed TIN for the reservoir "Gradče". Because of the high density of the measuring route the TIN shows uniform transition of the bottom of the reservoir without some visible breaks.
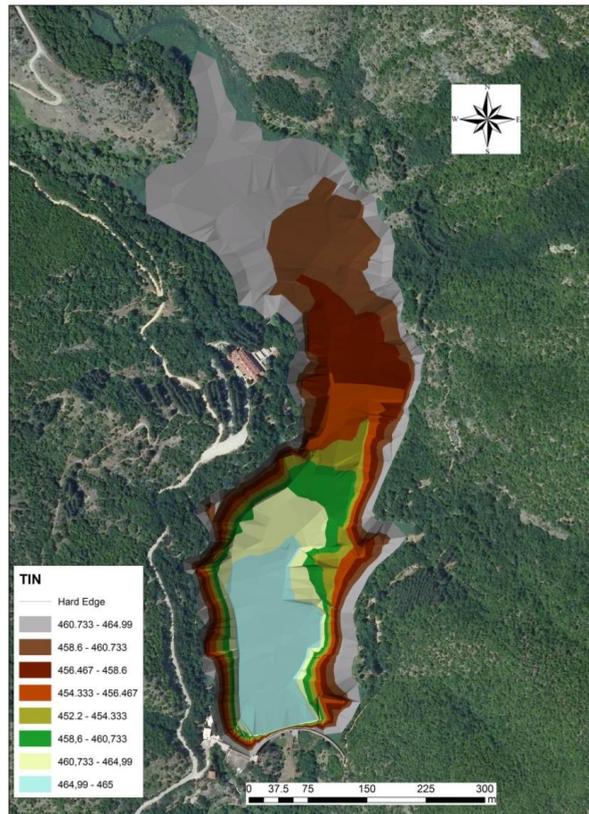

Figure 6. TIN of the reservoir "Gradče"

  The volume of the deposed sediment was calculated using ArcGIS . The reservoir "Gradče" is projected with a total storage volume of 1.8 million m^3 of water. The bathymetric measurements in 2013 showed that it is accumulated 554,908 m^3 or on average annually it was accumulated 10,267 m^3 of sediment. For the period 1984-2013 it has been accumulated 134,743 m^3 or 6,125 m^3/year or specific 69.77 m^3/km^2/year.
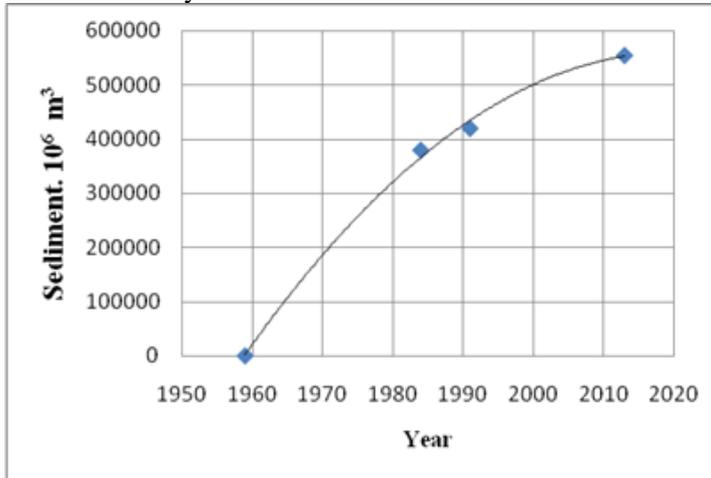

Figure 7. Dynamic of sedimentation of sediment material in the reservoir "Gradče"

CONCLUSION

  From the previous and current measurements can be seen a clear trend of decrease of filling the reservoir with sediment. In the period 1959-1984 the average annual deposition of the reservoir is 15.200 m^3/year and for the period 1984-2013 1984 the average annual deposition of the reservoir is 6,125 m^3/year. This is a decrease of the total deposition by more than 2.5 times.

  The used measuring method, combination of contour and cross-profile measurement, shows promising results. The main advantage of this method is that it uses GNSS support and the measurements are always with geographic reference. The main drawback is that it takes more time than the classical cross-profile bathymetric measuring. On the other hand, the time spent on the field is returned in the post-processing of the data. Namely, once the measurement are transferred into GIS environment, the post processing of the data takes less time than the cross-profile measurement. Also the new method gives the opportunity for almost total measurement of the reservoirs.

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